Channel Modelling For Underwater Wireless Communication System

A Thesis submitted in partial fulfilment of the Requirements for the degree of

Master of Technology

In

Electronics and Communication Engineering

Specialization: Communication and networks

By

PRATHAMESH VIVEK KITTUR

ROLL NO: - 213EC5243

Department of Electronics and Communication engineering

National Institute Of Technology,

Rourkela

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PRATHAMESH VIVEK KITTUR

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Under guidance of

Prof. Sarat K. Patra

Department of Electronics and Communication engineering

National Institute Of Technology,

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Odisha 769008

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DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA
ODISHA, INDIA – 769008

CERTIFICATE

This is to certify that the thesis entitled "*Channel Modelling For Underwater Wireless Communication System"* submitted by Mr. Prathamesh Vivek Kittur bearing roll no. 213EC5243 in partial fulfillment of requirement for the award of Master Of Technology in Electronics and Communication engineering with specialization in "Communication and Networks" during session 2013-15 at National Institute Of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any other Degree/Diploma

Date: - 25 May, 2015

Place: - Rourkela

Prof. Sarat K. Patra

Dept. of Electronics and Communication Engineering

National Institute Of Technology, Rourkela

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Prathamesh Vivek Kittur

Roll No:-213EC5243

Dept. of Electronics and Comm.Engg

National Institute Of Technology,

Rourkela

Date: - 25 May, 2015

Place: - Rourkela

Dedicated to my family, my respected teachers and my friends

ABSTRACT

Now a days, underwater wireless communication is getting lot of popularity. Few years before it was related only to military and defense applications. But now it is used in commercial field also.

Design of Underwater wireless communication is very difficult as behavior of water is completely different than air. We have to take lot of parameters into consideration at the time of design. Also, the losses and noise are comparatively very high in underwater than that of in air. Hence long distance communication is practically very difficult to design.

The Electromagnetic waves (EM), Magnetic Induction (MI), Optical waves or acoustic waves are the choices for underwater wireless communication systems. Out of these, acoustics are proven to be best underwater although they are limited with bandwidth due to thermal noise. But still acoustics provide communication at large distance comparing to other due to its special property of low attenuation of sound underwater. The currently favorable technology for underwater communication is upon acoustics.

In this thesis we present the parameters of acoustic channel, characteristics of acoustics, its mathematics and analysis. Also, we take a look at modulation technique that can be used in transmitter and receiver.

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ACRONYMS

ASK	Amplitude shift keying
AUV	Automotive underwater vehicle
BER	Bit error rate
BT	Bottom type
EM	Electromagnetic
FSK	Frequency shift keying
LOS	Line of sight
MI	Magnetic Induction
PSK	Phase shift keying
QPSK	Quadrature phase shift keying
SNR	Signal to Noise ration
Turbo	Turbulence
UWCN	Underwater wireless communication

1 Introduction to underwater wireless communication system

Contents:-

1.1 Background

Around 70% of the surface of earth is covered with water. It contains large amount of energy and natural resources and hence for exploring these resources, development of effective underwater wireless communication system became very important. Due to number of applications like scientific marine exploring, pollution controlling, voice and data communications between divers, mine reconnaissance, study of disasters, military projects, etc. the field of underwater wireless communication is rapidly increasing. Also, shipbuilding and offshore engineering is taking lot of interest in it. So, obviously it is one of the important communication media for communication researchers.

Underwater wireless communication is an enabling technology for oceanography and its applications. It consists of number of vehicles with attached sensors for monitoring the given area.

But, development of underwater wireless communication system is not that much easy as it is totally different from terrestrial radio environment both in terms of energy, cost and channel propagation.

Major challenges encountered in the design of underwater acoustic networks are as follows [16]

- The available bandwidth is very limited which causes reduction in transmission range
- The underwater channel is mainly impaired due to multipath and fading
- Propagation delay in underwater wireless communication is five times higher than RF terrestrial channel
- Underwater sensors are very costly. And very high protection is required for these sensors. Also most of the times they fail due to corrosion
- Battery power is very limited and it can't be charged as solar energy can't be exploited.

Out of EM, MI and acoustic waves most of the applications are done by using acoustics as they are proven to be excellent in underwater compare to others as they provide wide range up to 10 km with very small antenna size nearly about 0.1m. Also, power loss in underwater acoustics are very small compare to EM and optical waves in sea environment.

The basic problems in front of underwater acoustic communication are limited sound velocity, absorption of a sound in water, multipath propagation, ambient noise, Doppler's spread, etc.

Small change in sound velocity also causes lot of effects on underwater communication system. Multipath propagation is due to the surface reflection and bottom reflection and mainly present in shallow water. Attenuation is introduced in a system when acoustic energy is partially transform into heat and lost due to scattering. If transmitter and receiver both are moving then Doppler spread occurs which is mainly present in AUV's. These parameters highly affect communication signal and reduces data rate significantly but still underwater wireless communication is very important field and an interest of researchers due to following applications.

1.2 Applications of Underwater wireless acoustic networks

The applications of underwater wireless communication are given in terms of environmental, marine, scientific and military system. Table 1.2 gives applications of UWCN. [16]

Environmental	**Marine**	**Scientific**	**Military**
Pollution	Finding natural resources	Oceanography	Bottom imaging
Finding oil and gas sources	To study marine life	Geo sciences	Detection of underwater objects
Protection of ships	Finding resources in deep sea	Marine biology	Threat detection
Weather study	Pollution controlling	Seismic study	AUV controlling

Table 1.1 Applications of wireless communication

1.3 Overview of underwater wireless communication

Underwater wireless acoustic communication system is a two way communication system in which digital data is converted into special underwater sound signals [1]. Then these signals are received by another transreceiver and then converted back to digital data. This communication is done in multipath propagation of acoustic/sound signal.

Figure 1.1 gives brief idea about underwater wireless acoustic communication.

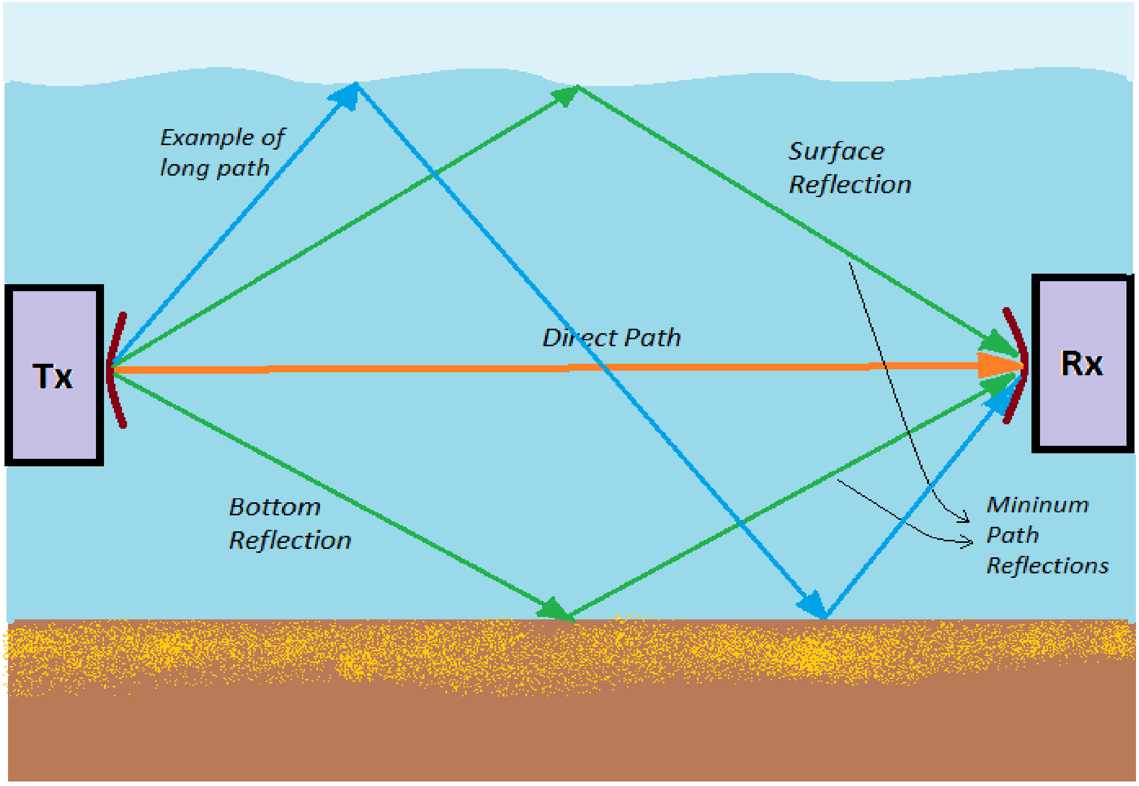


Figure 1.1: Overview of Underwater wireless communication

The underwater wireless communication is come in to picture in 1940 when Leonardo Da Vinci said, *"If you cause your ship to stop and place the head of long tube into water and place extremity to your ear you will hear sound of ships standing at a long distance from you"*. In 1912, after incidence of Titanic, systems for detection of icebergs are developed which are also used in World War.

As shown in figure 1.1, underwater wireless communication consists of a transreceiver with antennas and sensors attached to them. As discussed above underwater sensors are coated very carefully to protect them from corrosion. We can transmit EM or acoustic wave but acoustics is a main choice as it gives better result and better range.

Due to attenuation, the transmitted signal transmits in a form of multipath. At receiver every multipath signal must be recovered to get original signal back. The reflection of these multipath signals is of two types a surface reflection and bottom reflection. Surface reflection depends upon surface properties while bottom reflection depends on bottom type and sand properties. As, some multipath signals become long path signals and some signals become short path signals hence propagation delay for every multipath signal is different which increases overall propagation delay of a transmission signal.

If we use acoustic waves for transmission then it mainly affects due to thermal noise and converts into heat which reduces system efficiency hence, usually 20 KHz to 100 KHz frequency band is selected for acoustics.

1.4 Data Range for underwater acoustic communication [19]

Range	**Frequency**
1000 Km	Less than 1 KHz
Up to 100 Km	2 to 5 KHz
Up to 10 Km	Nearly 10 KHz
Up to 1 Km	20 to 50 KHz

Table 1.2: Data Range for underwater wireless acoustic communication

1.5 Thesis organization

This thesis is organized into 6 chapters. The current chapter begins with background of underwater wireless communication. The objective of thesis is framed after overview and chapter ends with outline of thesis.

*Chapter 2:-*Chapter 2 deals with comparison of EM, MI, Optical and acoustic waves. It gives brief idea about advantages of acoustic waves over electromagnetic waves for underwater wireless communication.

Chapter 3:-

Chapter 3 discuss about all acoustic properties under water. It gives brief idea about calculation of acoustic velocity under water and its effects. It also discuss about important parameters like attenuation, absorption and noise.

Chapter 4:-

Chapter 4 discuss about different modulation techniques with its advantages and disadvantages. Also it discuss about the reason to use QPSK transmitter and receiver for current system.

Chapter 5:-

Chapter 5 deals with simulation model for underwater wireless communication. In this chapter we focus on QPSK transmitter and receiver blocks and its working functionality. Also, this chapter gives brief idea about Rayleigh fading channel for UWCN. In this chapter bit error rate determination is done and constellation diagram and BER plot is presented.

2 Comparison of EM, MI and acoustic waves

Contents:-

- EM Waves
- Magnetic induction waves
- Optical waves
- Acoustic waves

2.1 EM Waves

EM waves are the waves with frequency between **400 MHz** to **300 GHz**. They are very good for short distances and proven better in shallow water but for deep underwater and salt water it fails.

Following parameters and simulations will give brief idea about EM waves.

2.1.1 Attenuation

We know that, EM waves are highly influenced with conduction. If the conductivity of water is very high then attenuation also increases to high because during transmission lot of energy is generated in a form of heat which leads to attenuation [2] [3].

If attenuation is high, then it affects system very badly and data rate becomes very low. Hence, attenuation should be as small as possible. The attenuation of EM waves on terrestrial ground and in underwater are completely different. Calculation of attenuation for EM waves is given in equation 1.1.

Generally, average conductivity of saltwater is ***4 s/m***

While ***0.01 s/m*** for freshwater [3] [4].

Attenuation of an EM wave is calculated using a formula [4],

$$\propto = 0.0173\sqrt{f.\sigma} \ldots\ldots\ldots \text{(1.1)}$$

Where,

α = attenuation in dB/m

f = operating signal frequency in Hz

σ= conductivity in S/m

Hence, from simulation we got the following result shown in figure 2.1.

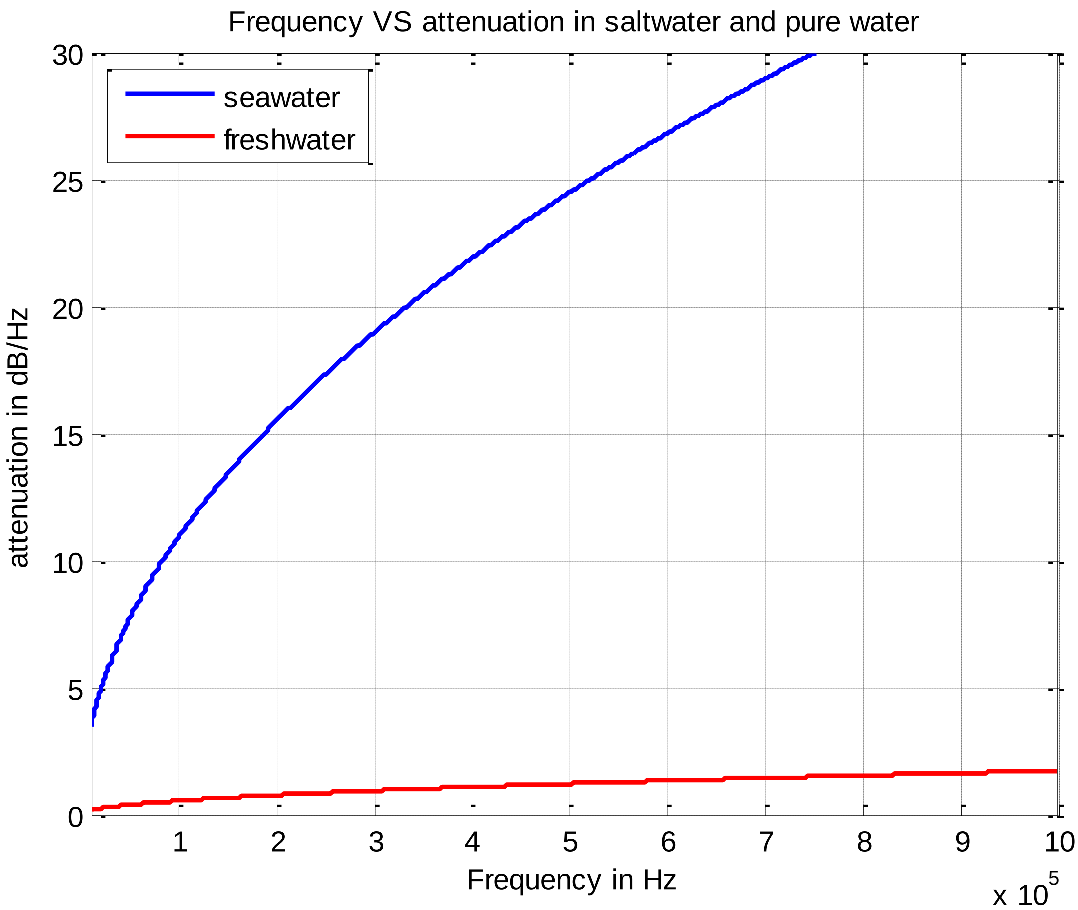


Figure 2.1: Attenuation due to EM waves under water

From ***figure 2.1***, we can say attenuation in seawater is extremely high in comparison with freshwater.

At 100 KHz the attenuation is up to 10dB/Hz for saltwater which is very high in comparison with 1dB/Hz in pure water.

As frequency increases the attenuation also increases which degrades system. Hence, transmission with high frequency is impossible.

2.1.2 Wavelength

Now let's consider in terms of wavelength. We know that the wavelength in air can be calculated by formula,

$$\lambda = \frac{c}{f} \dots\dots\dots \text{(2.1)}$$

Where, c = 3 X10^{8,} that is velocity of light

f= 10 KHz = 10.10^{3} Hz

Hence, λ = 30 Km

Now, for underwater wavelength can be calculated by formula [3],

$$\lambda = 1000\sqrt{\frac{10}{f.\sigma}} \dots\dots\dots \text{(2.2)}$$

Considering sea water conductivity is given as,

$\sigma = 4\ S/m$

Hence, after calculations

$$\lambda = 1000\sqrt{\frac{10}{10\text{KHz x } 4}}$$

$$\lambda = 15.81\ \text{m}$$

Which shows that for salt water the transmission range of EM waves is extremely low. For 10 KHz in air we can transmit data up to 30 Km but in salt water its range become nearly 15 m.

Where, for shallow water

$\sigma = 0.01\ S/m$

Hence,

$$\lambda = 1000\sqrt{\frac{10}{10\text{KHz x } 0.01}}$$

$$\lambda = 316.2278\ \text{m}$$

It shows that transmission range of EM waves in shallow water is better than that of salt water but still not good enough compare to terrestrial ground.

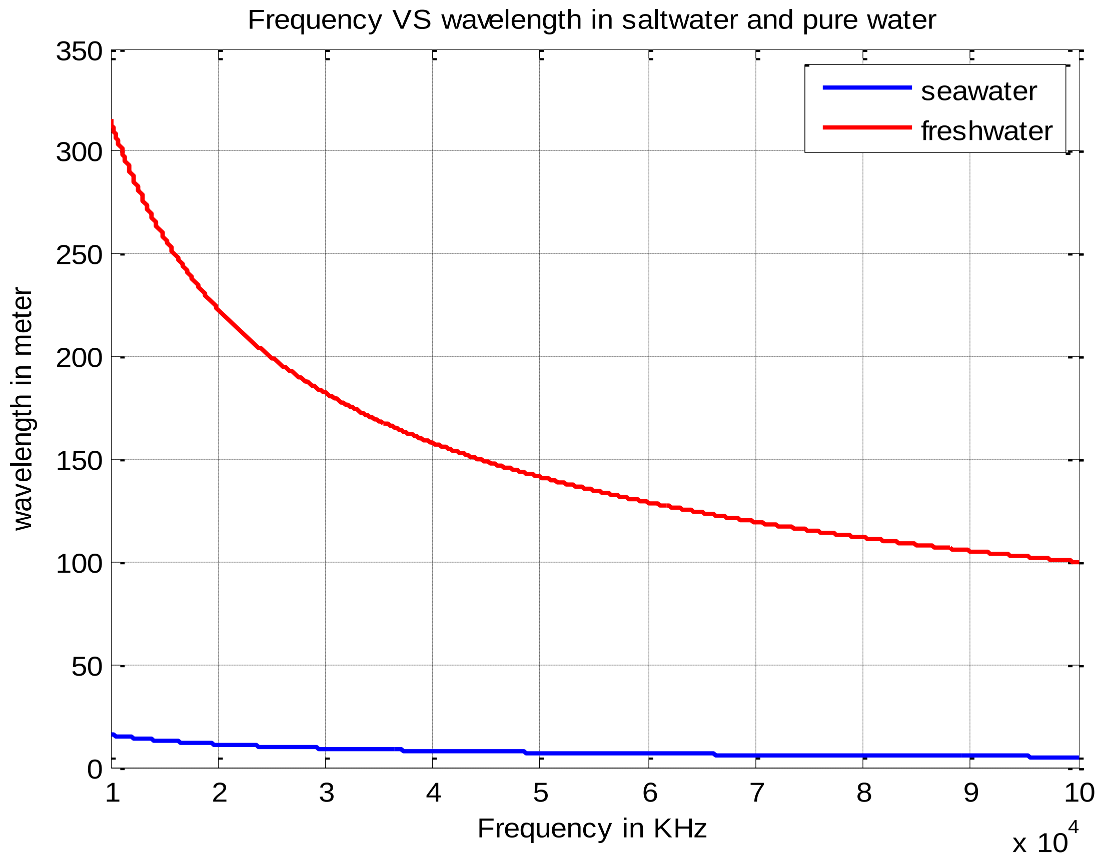


Figure 2.2: Wavelength of EM waves under water

Hence, from ***figure 2.1 and figure 2.2*** we can say that we can use EM waves for freshwater but not for saltwater due to large effect of conductivity on wavelength and attenuation.

Following table gives brief idea about EM range and data rate. [5]

Medium	**<10 m**	**50 m**	**200 m**	**>1 Km**
Sea water	Up to 8 Kbps	300 bps	25 bps	1 bps
Fresh water	Up to 3 Mbps	150 Kbps	9 Kbps	Up to 300 bps

Table 2.1: EM Range and Data Rates

2.2 Magnetic Induction (MI) waves

MI waves came into a picture of underwater wireless communication design to reduce a path loss. Basically, MI waves are tolerant to losses and they usually don't impact on marine life. Even they are very immune to acoustic noise which is a better property of MI waves. It can't be affected by multipath propagation or fading. Also Magnetic Induction waves provide superior bit error rate in fresh water.

Magnetic induction can give important applications like diver-to-diver communication, voice and text telecommunication, real time data transfer between AUV's. Telemetry and remote control from underwater or surface equipment is also possible.

The performance that researcher got by using MI waves underwater is fair enough but still they can't use for long distance communication due to following reasons [6].

- The basic operating frequency of Magnetic Induction waves is started with 500 Hz which is very low compare to EM and acoustics.
- The magnetic antennas work finely in salt water at low frequencies only.
- As frequency increases, the introduction of eddy current due to conductivity also increases which increases attenuation and affects system badly.
- Eddy current generated due to MI waves waste lot of energy which reduces efficiency of communication system.

Hence, MI waves are also not used in Underwater for long distance communication.

2.3 Optical Waves

Optical waves are known for extremely high bandwidth. Also, they are usually come in low cost but still they are not an option for underwater wireless communication either due to following reasons [7].

- Optical waves require a line of sight communication which is practically impossible for underwater
- Optical waves can't be useful in direct communication underwater because they can't cross water boundary over large distance.

- The impact of marine life on optical waves is extremely high compare to EM, MI and acoustic waves which reduces its strength considerably.

The range of optical waves is extremely low due to these reasons. Hence, optical communication is not a good option for underwater wireless communication.

2.4 Acoustic Waves

Acoustic waves are proven and now a days mostly preferable technology due to its long transmission capability at small frequencies. It can travel up to 200 Km. They provide stable characteristic properties at long distance. Also Acoustics have excellent proven characteristics for both transmitter and receiver as in terms of transmission the results through acoustics under saltwater are far better than EM waves.

In next chapter details about ocean acoustics are given.

3 OCEAN ACOUSTICS AND ITS CHARACTERISTICS

Contents:-

- Acoustic waves underwater
- Absorption and path loss
- attenuation
- Noise
- Parameter table of design

3.1 Acoustic waves underwater

The frequencies between ***0 KHz*** to ***100 KHz*** are generally chosen for underwater acoustic communication [8] [9]. In case of acoustics we have to consider attenuation, absorption and ambient noise which are key parameters for characterization and modelling of channel. The main problem during design of a channel is, all these parameters increase with increase in frequency and affect communication system badly. Hence, proper selection of a frequency for underwater is a key thing for good system design.

Also we have to consider sound velocity under water as small change in sound velocity affect system very badly.

3.1.1 Sound Velocity

Generally, changes in sound velocity are smaller but small changes in sound velocity reduces strength of system.

Sound velocity underwater mainly depends upon three main parameters temperature, salinity and underwater depth.

The sound velocity underwater is calculated by the formula [10],

$C = 1449.2 + 4.6.T - 0.055.T^2 + 0.00029.\ T^3 + (1.34 - 0.01.T).\ (S-35) + 0.016.Z...$ (3.1)

Where,

C = sound velocity underwater

T= Temperature underwater

S= Salinity of water

Z= underwater depth

In case of deep sea, salinity is generally considered as constant 35 Ppm because in deep underwater the effect of salinity on sound velocity is negligible.

Generally, the parameters are chosen between following range [10]

Temperature	0 to 35 degree
Salinity	0 to 35 Ppm
Depth	0 to 1000 m

Table 3.1: Conditions for underwater wireless communication

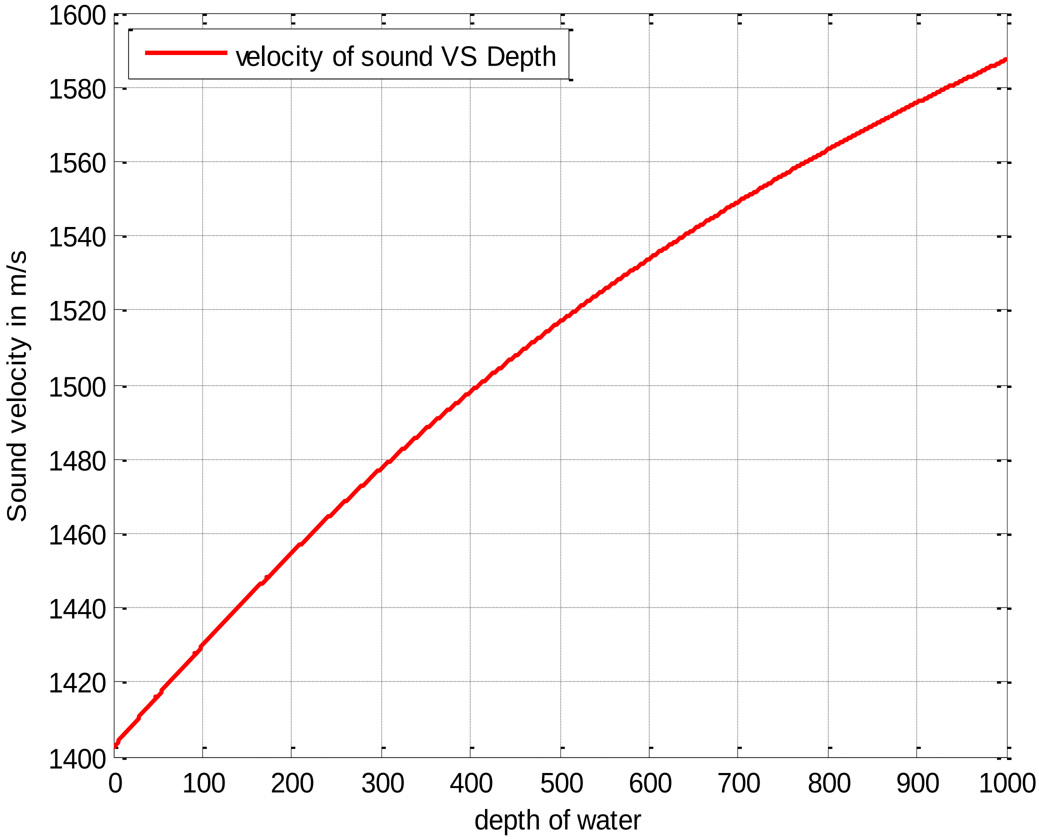


Figure 3.1: Sound velocity under water

The sound velocity in air is generally 340 m/s-400 m/s but in underwater it is around 1400m/s which is far better than that of air as shown in figure 3.1. Hence, it proves why acoustics are chosen in underwater.

Generally, sound velocity under sea level is within the range of 1400 m/s to 1600 m/s.

3.1.2 Absorption and path loss

We know that, due to thermal generation heat is produced under water which become the reason for absorption and path loss. Hence, it degrades amplitude of a system.

Calculation of absorption coefficient is extremely important to calculate overall path loss and also we have to consider cylindrical loss or spreading loss to calculate overall path loss.

During the transmission of sound signal from acoustic source to the reception, the signal energy is one of the important factors that which affects signal-to-noise ratio of receiver. The absorption loss of sound energy is the main part of the attenuation loss, and the absorptions are usually seawater medium absorption and interface medium (such as the benthal) absorption. For acoustic frequencies more than 1 kHz, seawater acoustic absorption is the main factor which causes acoustic wave attenuation and is proportional to the square of the wave frequency. The formula for calculation of absorption coefficient is given by Thorp.

According to Thorp’s formula [10],

$$\alpha = 0.11.\frac{f^2}{1+f^2} + 44.\frac{f^2}{4100+f^2} + 2.75.10^{-4}.f^2 + 0.003 \quad \dots\dots (3.2)$$

Where,

α = absorption coefficient in dB/Km

f = signal frequency in Hz.

This formula shows that the absorption coefficient is directly dependent upon signaling frequency. So increase in frequency leads to increase in absorption. Hence, careful choosing of frequency is very important

Figure 3.2 shows relationship between absorption coefficient and frequency.

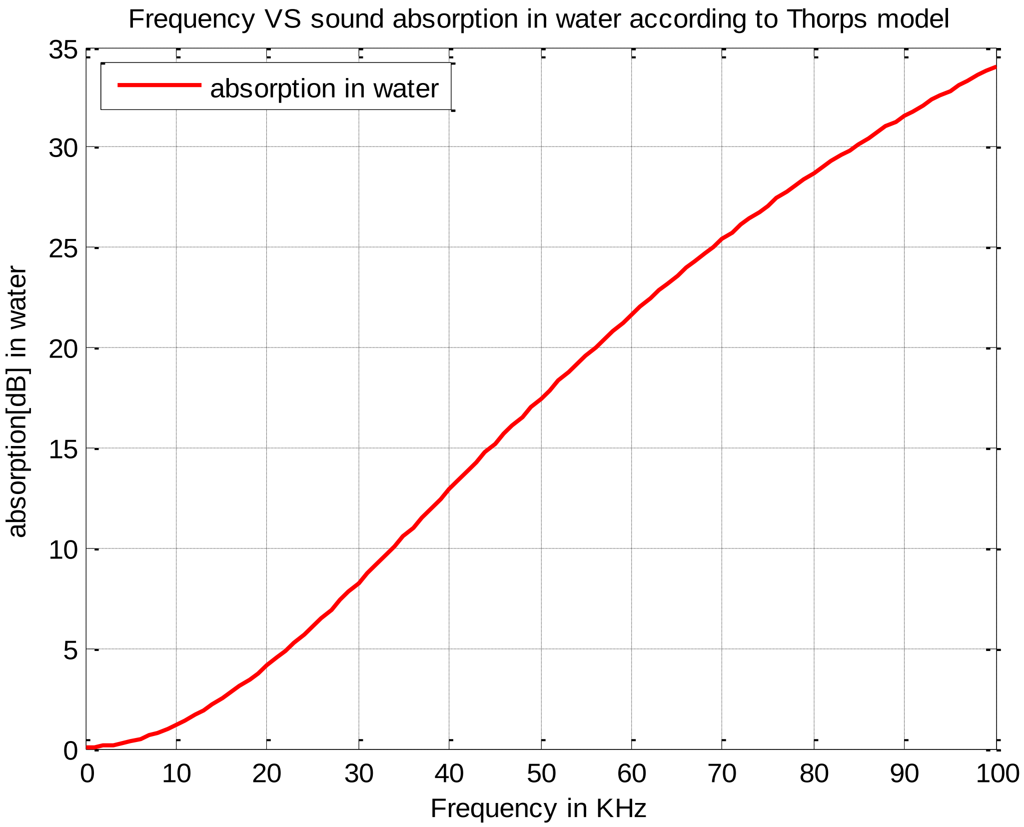


Figure 3.2: Frequency vs. Sound absorption in water

From figure 3.2, we can say absorption underwater strictly depends upon the signal frequency that we choose. By using absorption coefficient (α) we can calculate overall path loss by using formula [10] [11],

$$A(L,f) = L^k.\alpha(f)^L \text{...........} \quad (3.3)$$

Where,

α = absorption coefficient

k = spreading loss

L= transmission distance

Generally, we choose value of spreading loss as 1.5 [11] and the value of spreading loss is always between 1 and 2.

3.1.3 Attenuation

While calculation of attenuation, we have to consider attenuation due to saltwater, attenuation due to sediment and attenuation due to surface. Out of these, attenuation due to surface is very small and can be neglected. But attenuation due to bottom must be considered while developing a system for shallow water. The attenuation due to bottom depends upon bottom type.

According to Francois and Garrison formula [12],

$$\beta = \frac{A1.P1.f1.f^2}{f1^2 + f^2} + \frac{A2.P2.f2.f^2}{f2^2 + f^2} + A3.P3.f^2 \dots\dots(3.4)$$

Saltwater is a mixture of Boric acid, Magnesium sulphate and pure water. First term in a formula denotes an attenuation for Boric acid while second term denotes attenuation for magnesium sulphate and third term denotes attenuation in pure water [13].

For B (OH) $_3$**,**

$$A1 = \frac{8.686}{c}.10^{0.78.PH-5} \dots\dots..(3.5)$$

$$P1 = 1$$

$$f1 = 2.8\sqrt{\frac{S}{35}}.10^{(4-\frac{1245}{T+273})} \dots\dots(3.6)$$

For MgSO $_4$

$$A2 = 21.44.\frac{S}{c}(1 + 0.025.T) \dots(3.7)$$

$$P2 = 1 - 1.37.10^{-4}.Z + 6.2.10^{-9}.z^2 \dots\dots(3.8)$$

$$f2 = \frac{8.17.10^{(8-\frac{1990}{T+273})}}{1+0.0018(s-35)} \text{ ... .} (3.9)$$

At 15 ^{O}C,

For pure water,

$$A3 = 4.973.10^{-4} - 2.59.10^{-5}.T + 9.11\,.10^{-7}.T^2 - 1.5.10^{-8}.T^3 \text{ .....} (3.10)$$

$$P3 = 1 - 3.83.10^{-5}.z + 4.9.10^{-10}.z^2 \text{ ... ...} (3.11)$$

Where,

C= Calculated sound velocity underwater

T= Temperature in degree

Z= Depth underwater

S=salinity of water

PH= PH value of water generally taken as 8

Figure 3.3 indicates attenuation in saltwater due to Boric acid, Magnesium sulphate and in pure water [13].

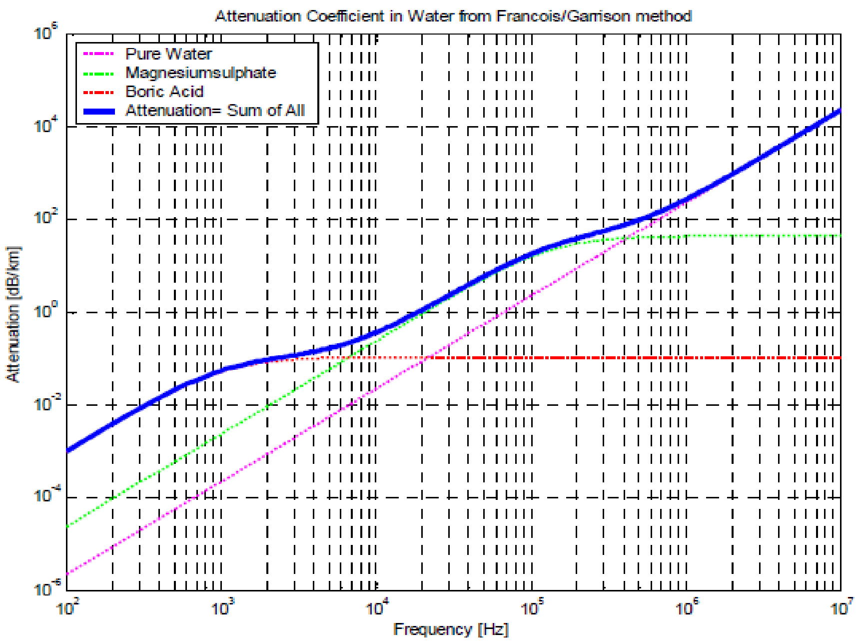


Figure 3.3: Attenuation coefficient in water from Francois and Garrison method

3.2 Attenuation due to bottom reflection

This parameter is also very important in terms of attenuation. Attenuation due to bottom reflection mainly depends upon bottom type or sand type lie very fine slit sand, fine sand, coarse sand or medium sand.

The calculation of sound attenuation due to bottom reflection is calculated by following formula [14].

$$s = \frac{1}{8.686}.K.(\frac{f}{1\,KHz})^{n}.(\frac{1}{m})\ldots\ldots\ldots \text{(3.12)}$$

Where,

Values of K and n are provided in following table.

Sediment type	**K**	**n**
Very fine slit	0.17	0.96
Fine sand	0.45	1.02
Medium sand	0.48	0.98
Coarse sand	0.53	0.96

Table 3.2: Sand types and its corresponding values

3.3 Ambient Noise

Ambient noise is one of the most important characteristics to be considered while channel modelling. There are different types of noises like noise due to heavy traffic of ships, noise due to rain, noise due to wind, noise due to earthquake or breaking of waves, etc.

Generally, we consider four noise as important during underwater communication design. They are as follows:-

3.3.1 Thermal Noise

For the signal frequencies more than 100 KHz, a noise generated due to random motion of water molecules is known as thermal noise.

It can be calculated as [15],

$$NL_{Thermal} = -15+20.\log (f)\text{.... } (3.13)$$

This is the most important parameter in noise to be considered as the design of a system depends upon the value of thermal noise. Large thermal noise affects data rate very badly. Frequency selection criteria mainly depends upon value of thermal noise as thermal noise totally depends on signal frequency. And as frequency increases thermal noise also increase as shown in simulation result.

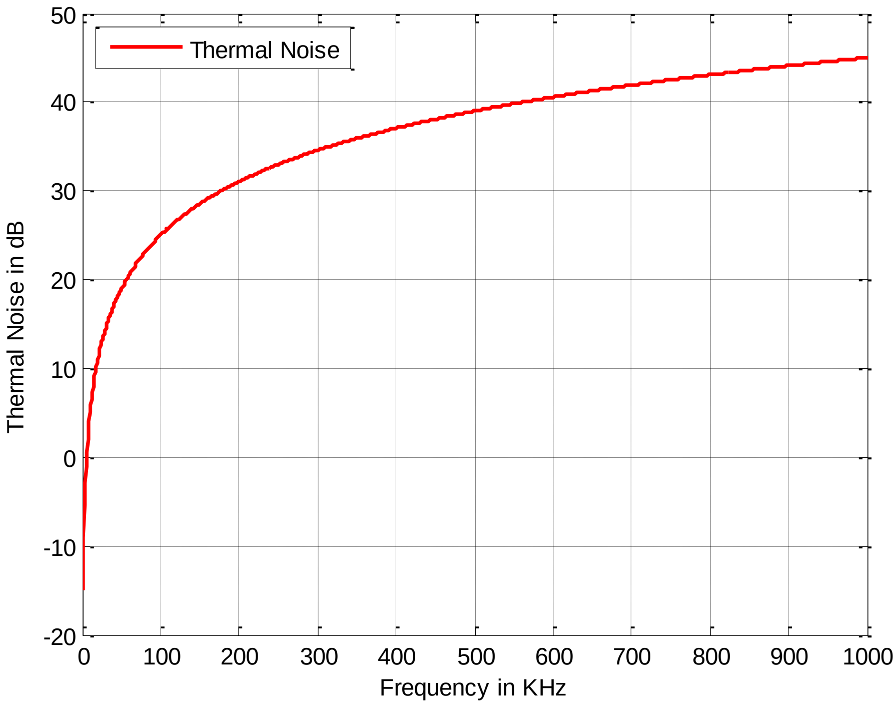


Figure 3.4: Thermal Noise Underwater

3.3.2 Turbulence Noise

For the frequencies from 50 Hz to 100 KHz, turbulence noise should be considered. Turbulence noise is generated in a system due to internal motions underwater like breaking of waves.

Formula for calculation of turbulence noise is [15],

$$NL_{\text{Turbulence}} = 17 - 30.\log(f) \quad \ldots. \ (3.14)$$

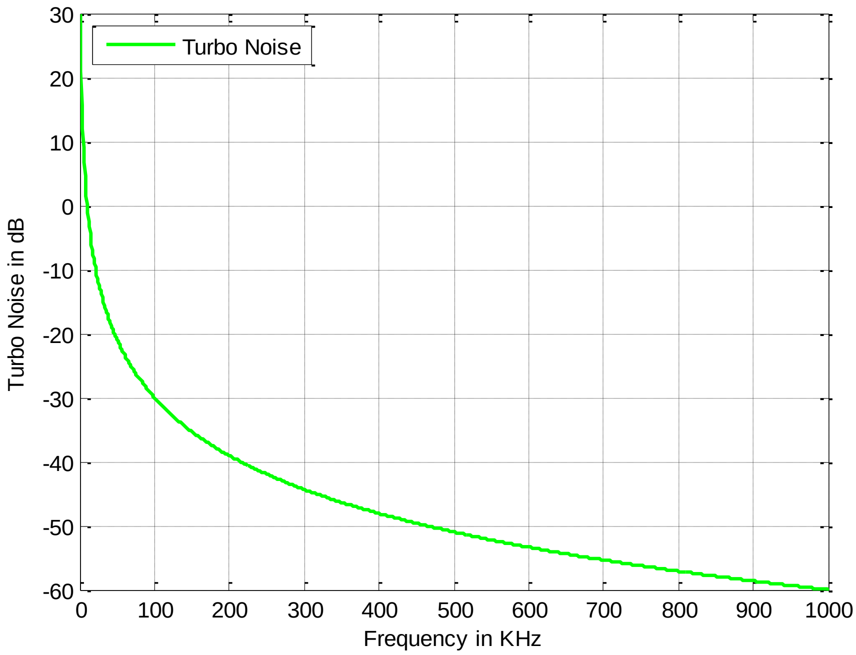


Figure 3.5: Turbulence Noise Underwater

3.3.3 Shipping Noise

Shipping noise is due to heavy traffic of ships in water. This noise is dominant at very low frequencies usually from 20 Hz to 500 Hz. As frequency increases, shipping noise decreases rapidly.

It can be calculated as [15],

$$NL_{shipping} = 40 + 20\,(s-0.5) + 26.\log(f) - 60.\,\mathrm{Log}\,(f+0.03) \quad \ldots..(3.15)$$

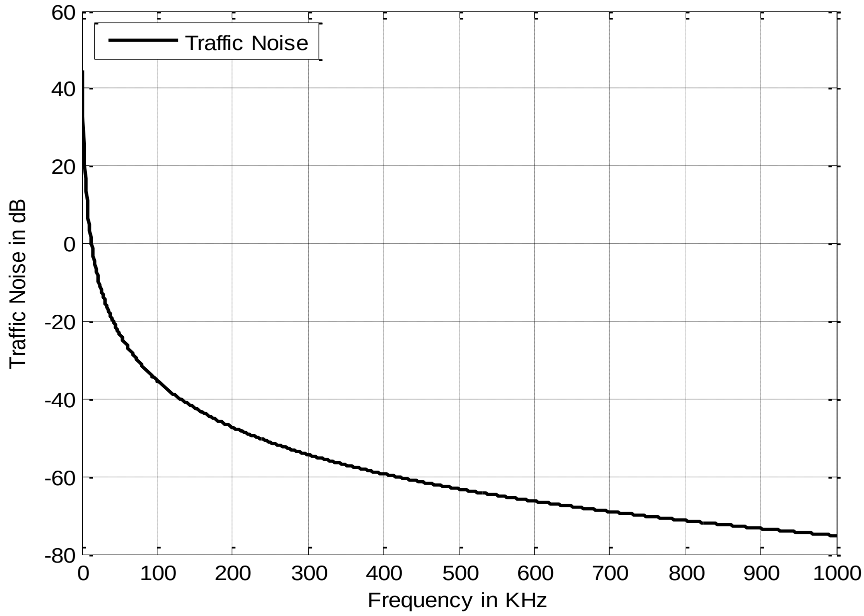


Figure 3.6: Shipping Noise Underwater

From figure 3.6 we can see that the traffic or shipping noise is dominant up to very low frequencies after certain 1 KHz it decreases below 0 dB and can be neglected

3.3.4 Sea state/wind noise

Sea state noise is typically dependent on wind speed. For frequencies more than 500 Hz it can be avoided. Because as frequency increases, effect of wind noise decreases. Hence domination of this noise on a system becomes negligible.

Formula for calculation of a wind noise is given as [15],

$$NL_{sea\ state} = 50 + 7.5.w^{1.2} + 20.\log(f) - 40.\,\mathrm{Log}\,(f+0.4) \ldots..\ (3.16)$$

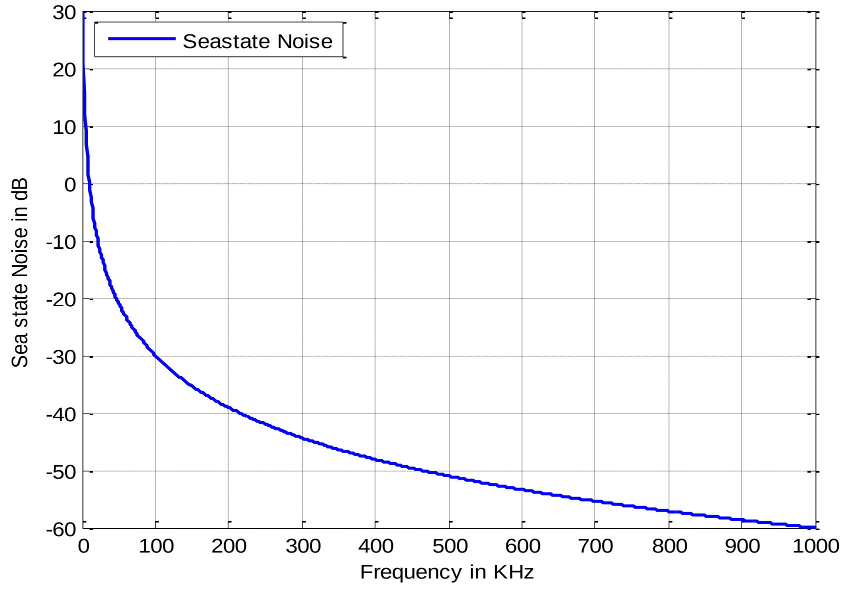


Figure 3.7: Sea state Noise Underwater

3.3.5 Total Noise

Hence, total noise can be calculate as [15],

$$NL_{total} = NL_{Thermal} + NL_{Turbulence} + NL_{shipping} + NL_{sea\ state} \quad \ldots\ldots\ldots \quad (3.17)$$

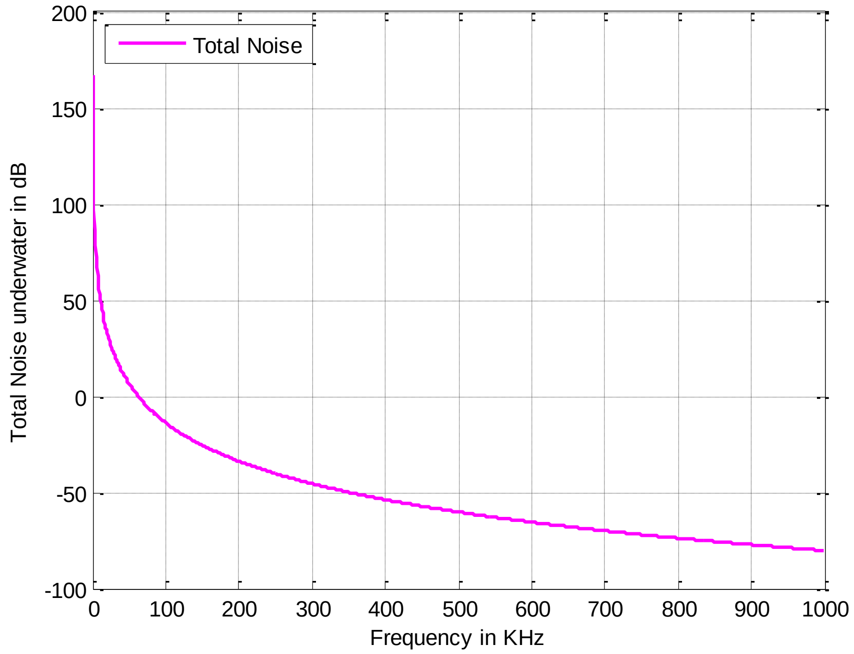


Figure 3.8: Total Noise Underwater

The total noise in underwater wireless communication decreases with increase in frequency, but as thermal noise is extremely dominant and it increases with increase in frequency. Hence, overall selection criteria for acoustics is from 0 KHz to 100 KHz.

Table 3.4 gives brief idea about selected and calculated components

3.4 Parameter table for design

Parameter	Selected/Calculated Value
Wind velocity	20 knots
Salinity	35 ppm
Temperature under water	15 degree Celsius
Underwater depth	1000 m
Signaling Frequency	35 KHz
Distance between transmitter and receiver (transmission distance)	100 m
Spreading loss	1.5
Sand Type	Very fine slit
Sound Velocity underwater	1522 m/s
Absorption Coefficient	10.57
Total Path loss	0.04
Total Attenuation	7.3388
Total Noise	16 dB

Table 3.3 Parameter Table

4 MODULATION TECHNIQUES OF COMMUNICATION

Contents:-

- Modulation and demodulation
- Amplitude shift keying
- Frequency shift keying
- Phase shift keying
- Quadrature phase shift keying

4.1 Digital Modulation Techniques

4.1.1 *What is modulation?*

Generally, the transmission of a message signal over a low frequency must be converted into higher frequency range, then it reduces the antenna size. And after successful transmission we can shift it back to original frequency range after reception. Consider one example, suppose we have frequency of 1 KHz. Hence, wavelength can be given as,

$$\lambda = \frac{c}{f}$$

That is $\lambda = 300\ \mathrm{Km}$

Design of an antenna for wavelength of 300 Km is practically impossible. Hence to reduce λ we have to increase the frequency. For this modulation technique is used. In short we can say modulation is defined as the process in which "*carrier signal is varied in accordance with message signal*". Generally, in modulation technique, the baseband signal is a "*modulating signal"* while the carrier signal is a high frequency sinusoidal signal.

4.1.2 *What is Demodulation?*

After the message is successfully received, it must be converted into its original format. This process is done by demodulation of a signal which is exactly inverse of modulation process.

4.2 Different modulation techniques

There are three basic modulation techniques also known as keying technique. These three techniques are based on three different parameters namely amplitude, frequency and phase. According to these parameters system performance can be analyzed. Each technique has its own advantages and disadvantages. They are as follows

4.2.1 Amplitude Shift Keying (ASK)

Amplitude shift keying is a technique in which the digital bit '1' is represented in the form of amplitude. If a transmitted signal transmits bit '1' then carrier is transmitted otherwise '0' is transmitted.

The demodulator at output side recovers the data in the form of amplitude keeping frequency and phase constant. Generally ASK is used to transmit data through optical fiber.

Constellation Diagram of ASK

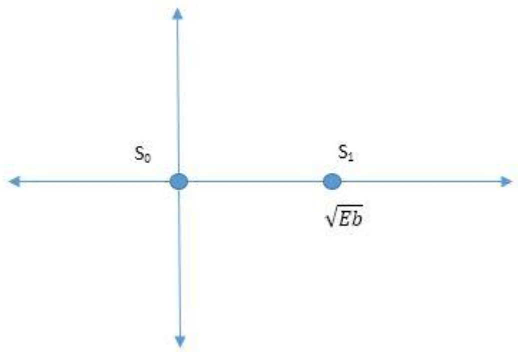


Figure 4.1: Constellation Diagram of Amplitude shift keying

Advantages

- Significant reduction in transmission energy
- Simplicity
- Easy to generate and detect

Disadvantages

- Easily influenced to noise interference
- It is used at very low data bit rates (usually 100 b/s)

Signal representation of ASK

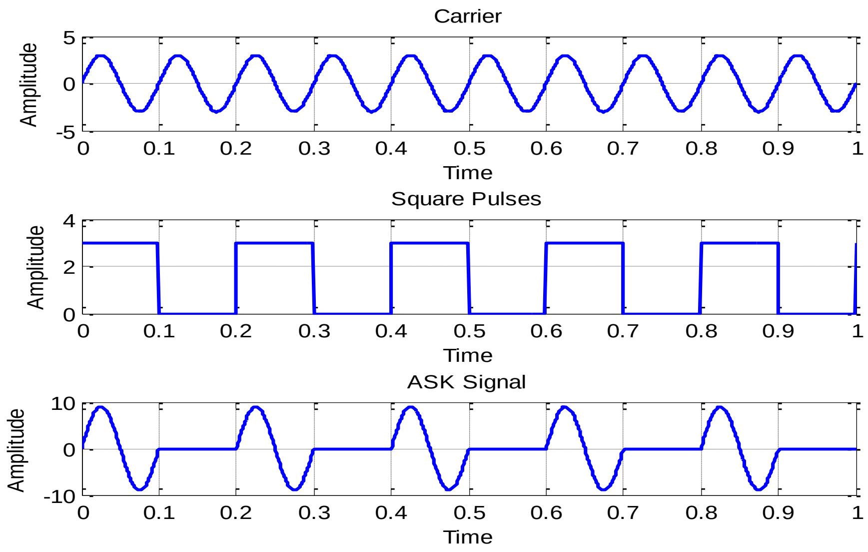


Figure 4.2: Signal representation of Amplitude shift keying

4.2.2 Frequency shift keying (FSK)

In frequency shift keying, sine wave is shifted in accordance with change in frequency. Bits ‘1’ and ‘0’ shows compression and expansion of a signal at output. The higher frequency given to bit ’1’ known as Mark Frequency where the frequency representing ‘0’ known as Space Frequency***.*** A modem converts binary data into FSK signal for transmission through telephone lines or wireless media. It is in a format of low and high state which is known by system.

Generally at the transmission input signal given is a NRZ signal.

Mathematically it is represented as,

$$s(t) = \begin{cases} Ac.\cos(2\pi f1t) & for\ m(t) = 1 \\ Ac.\cos(2\pi f2t) & for\ m(t) = 0 \end{cases} \text{.........} \quad (4.1)$$

Where, f1 and f2 are mark and space frequencies representing ‘1’ and ‘0’.

Constellation Diagram of FSK

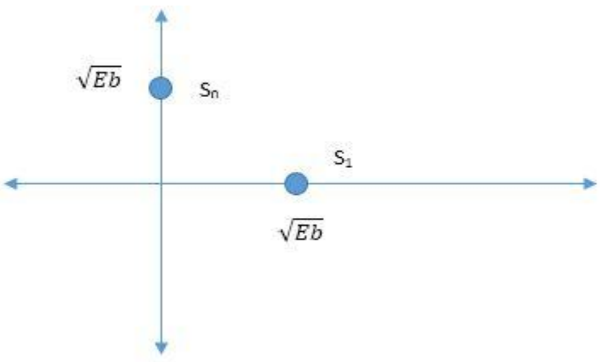


Figure 4.3: Constellation diagram of Frequency shift keying

Advantages

- Reduction in noise as amplitude is constant
- High data rate and greater signal strength

Disadvantages

- Requires very high bandwidth
- High complexity in circuitry

Signal representation of FSK

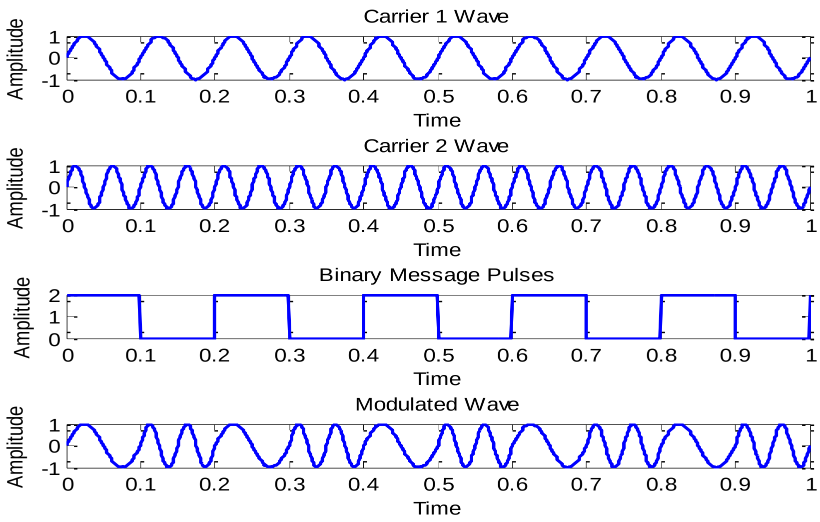


Figure 4.4: Signal Representation of Frequency shift keying

4.2.3 Phase shift keying (PSK)

Phase shift keying is a technique in which phase of a message signal is varied while transmission of a signal. The simplest technique of phase shifting in digital communication is Binary phase shift keying which is dependent on two phase angles 0 degree and 180 degree.

The digital transmission signal is divided into two parts and next bit is determined by taking a reference of a previous bit. For 0 degree the transmission of a bit is normal but when phase changes from 0 degree to 180 degree, transmission also changes from ‘0’ to ‘1’ or ‘1’ to ‘0’.

Mathematically it is represented as,

$$s(t) = \begin{cases} Ac.\cos(2\pi fct + 0) & for\ m(t) = 1 \\ Ac.\cos(2\pi fct + 180) & for\ m(t) = 0 \end{cases} \ldots\ldots\ldots (4.2)$$

Constellation Diagram of BPSK

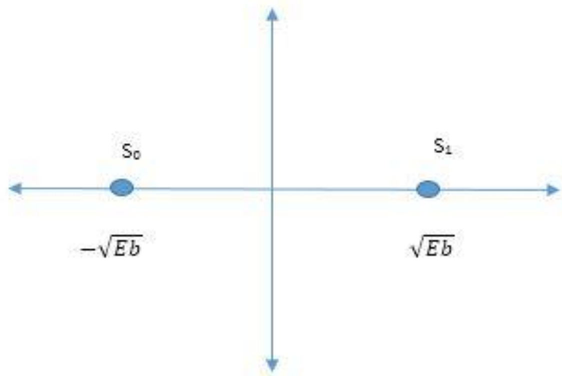


Figure 4.5: Constellation diagram of binary phase shift keying

Advantages of PSK

- High power efficiency
- Simple design
- Work very effectively at low transmission frequencies

Disadvantages of PSK

- Very low speed communication
- Low bandwidth efficiency
- Very low transmission power

Signal Representation of PSK

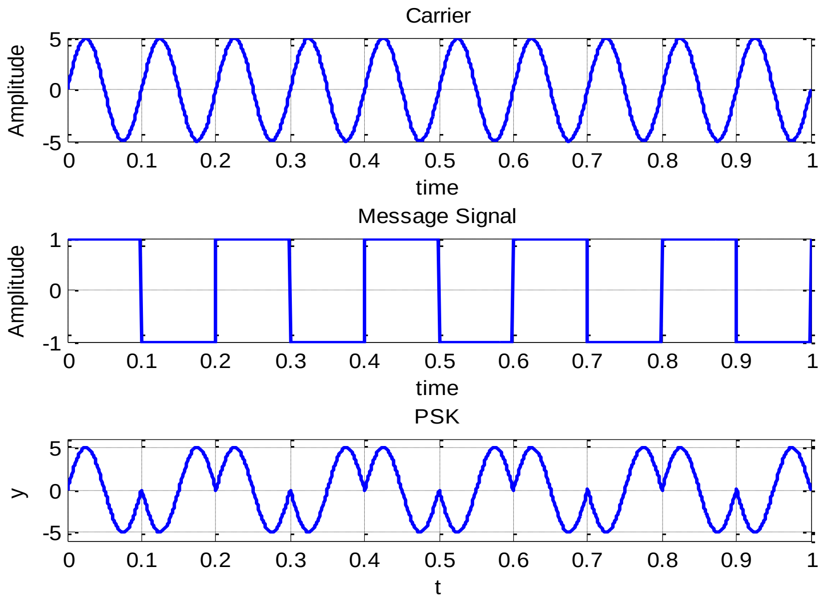


Figure 4.6: Signal Representation of phase shift keying

4.3 Quadrature phase shift keying (QPSK)

Digital modulation techniques need a set of basis function and they are chosen according to modulation scheme. Generally basis functions are orthogonal to each other.

"QPSK is a quadrature phase shift keying technique in which two sinusoids are taken as basic functions". Modulation can be done with the help of varying phase angles of the basis function which is dependent on message symbols. In QPSK every symbol is made up of two bits hence we can say that QPSK is a technique containing both phase and quadrature technique. The equation for QPSK is given as,

$$s_i(t) = \sqrt{\frac{2.E_b}{T}}.\cos(2\pi fct + (2n-1)\frac{\pi}{4} \quad \text{........ (4.3)}$$

Where,

n=1, 2, 3……….

Hence, for QPSK

- $s_i(t) = \sqrt{\frac{2.E_b}{T}}.\cos(2\pi fct) + \frac{\pi}{4}$ For bits '00'
- $s_i(t) = \sqrt{\frac{2.E_b}{T}}.\cos(2\pi fct) + \frac{3\pi}{4}$ For bits '10'
- $s_i(t) = \sqrt{\frac{2.E_b}{T}}.\cos(2\pi fct) - \frac{\pi}{4}$ For bits '01'
- $s_i(t) = \sqrt{\frac{2.E_b}{T}}.\cos(2\pi fct) - \frac{3\pi}{4}$ For bits '01'

And constellation diagram can be shown as,

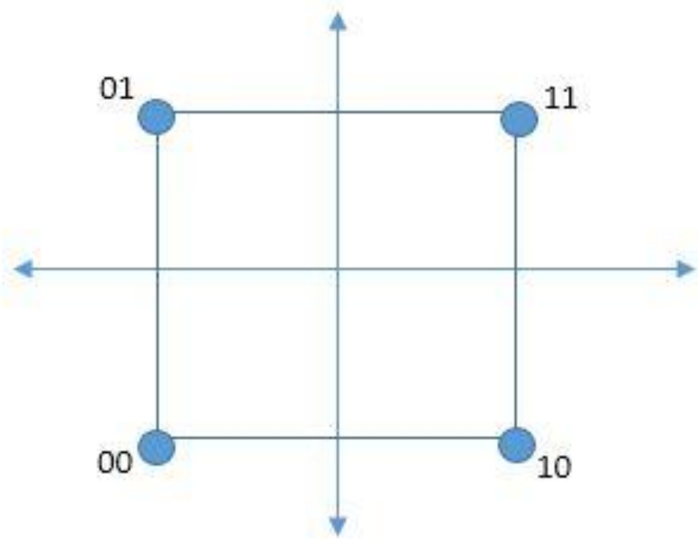


Figure 4.7: Constellation diagram of quadrature phase shift keying

Advantages of QPSK

- As QPSK requires half transmission bandwidth than BPSK, the bit error rate (BER) is also minimized twice of BPSK.
- The data rate is doubled that of BPSK
- Phase shift is not related to reference signal, it is related to phase of previously transmitted bits
- BPSK highly suffer with a phase shift problem but in QPSK signal is differentially encoded which reduces phase ambiguity.

Disadvantages of QPSK

- Inter channel interference is very high compared to BPSK
- QPSK is very sensitive to changes in phase.
- To reduce inter channel interference (ICI) QPSK requires very high quality filtering which increases complexity

5 SIMULATION MODEL FOR UNDERWATER WIRELESS COMMUNICATION

Contents:-

5.1 Simulation Model

The direct hardware implementation of underwater wireless communication system is very risky and expensive. Hence, simulation is a very good technique to implement the system virtually and see its effects. It provides the basic behavior of a system or more precisely we can say it gives an idea about the working of our design. By doing calculations we can predict how the system work when it will be implemented practically. It reduces our time as well as cost. We can't predict that direct hardware implementation will work correctly or not hence, simulation gives a platform to test the designed system virtually. Now we are developing a simulation system for underwater wireless acoustic communication.

Our simulation model can be expressed as,

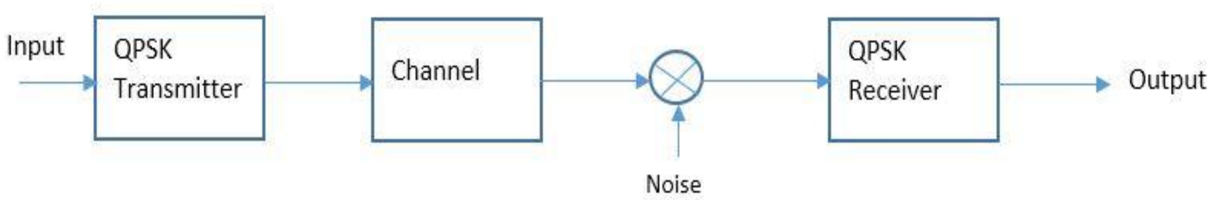


Figure 5.1: Simulation model for underwater wireless communication

We are going to use QPSK modulation technique for transmitter and receiver with Rayleigh fading technique to study properties of underwater. The channel shown in a diagram is an underwater which contains impediments like attenuation and absorption which causes path loss. The noise shown in given figure is an underwater noise which is externally added in a system. Digital bits are given as an input and are transmitted via QPSK transmitter. QPSK receiver is other end of a system which receives transmitted data and converts it back into original format

5.2 QPSK Transmitter

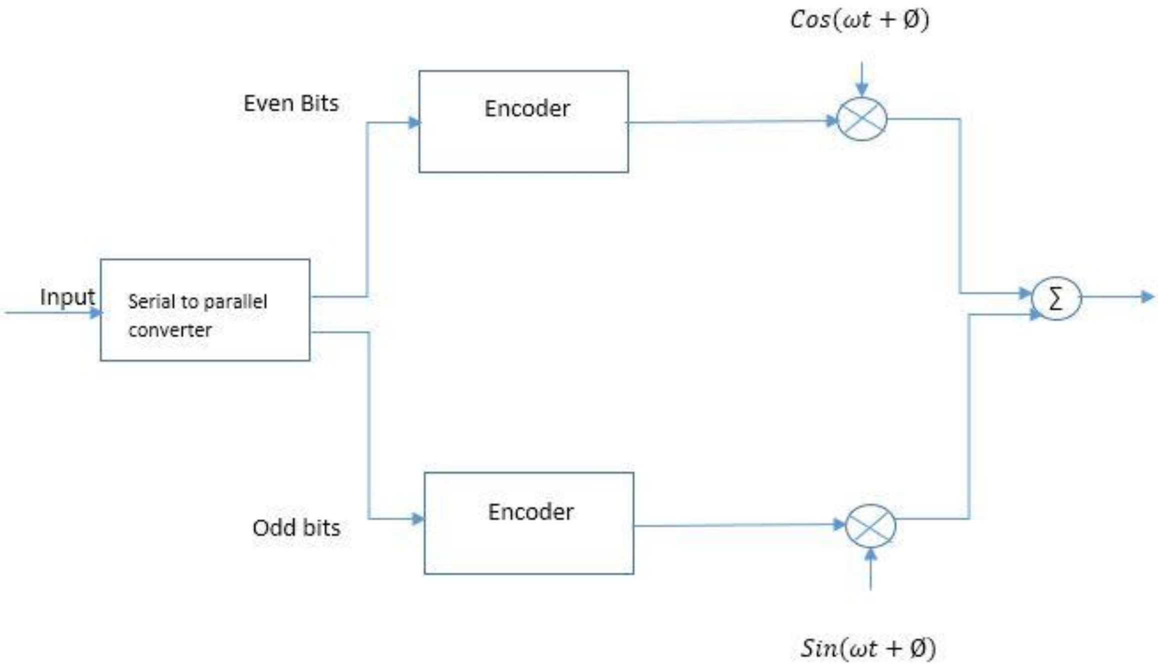


Figure 5.2: QPSK Transmitter

The diagram of QPSK transmitter is as shown in figure 5.2. The input in terms of binary 1 and 0 is given to the system. As discussed before, QPSK represents two bits per symbol hence while developing the system we have to work separately on even and odd bits. Serial to parallel converter converts the symbol in terms of even and odd bits [18].

Odd bit is treated as quadrature phase while even bit is treated as in-phase system. The basic concept behind QPSK transmitter is signal interval T should be twice of bit duration.

$$T = 2.T_b \ \ldots (5.1)$$

Hence from Eq 5.1, we can say that, for bit rate $R_b = \frac{1}{T_b}$ QPSK requires half transmission bandwidth in comparison with BPSK which makes it special. The bits are then encoded with an encoder. Odd bits are multiplied with sin (ωt +Ø) and even bits are multiplied with Cos (ωt +Ø) to transmit the signal.

5.3 Communication Channel

Channel is a media through which a signal is propagated. In our case, salt water of ocean is a channel medium through which we have to transmit the signal. As discussed before, the main problem of underwater channel is channel variation due to pH, temperature, salinity, underwater depth and interference.

These all parameters must be considered during channel modelling of underwater. We are considering multipath propagation and hence we are using Rayleigh fading channel technique for modelling our underwater channel [17].

Multipath propagation channel can be represented as,

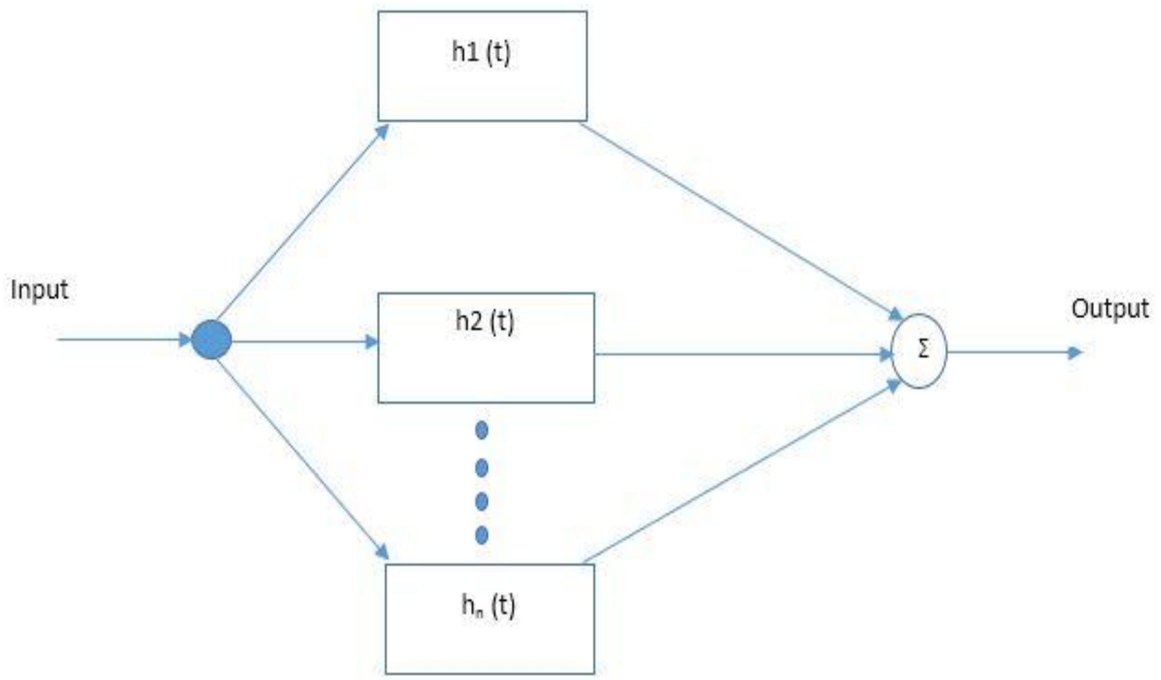


Figure 5.3: Communication Channel

Where, n denotes total number of multipath in underwater wireless acoustic communication system.

5.4 Rayleigh Fading

When transmitter transmit the signal, due to fading direct line of sight transmission becomes practically impossible and signals reach transmitter in multipath. Rayleigh propagation model is a statistical model which studies the behavior of different multipath propagation signals when there is no direct line of sight (LOS) path possible. [17]

Rayleigh fading channel is useful where a transmitted signal transmits in a form of multipath and no single path is dominant.

Due to environmental conditions, signal scatters between transmitter and receiver and no single path remains dominant and reception of every path becomes necessary.

Rayleigh Fading Channel Model For Underwater

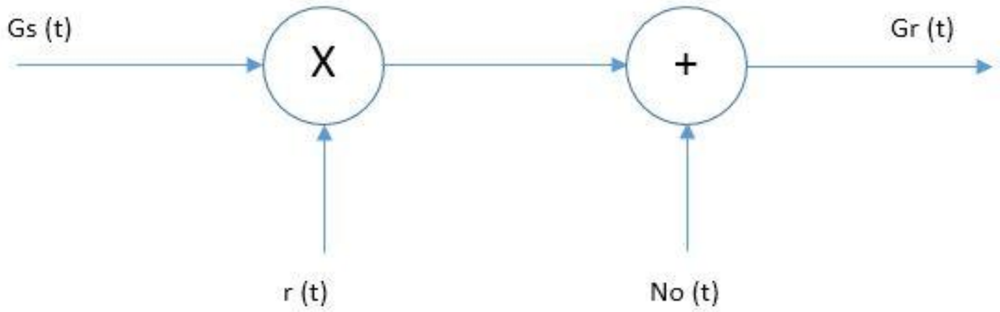


Figure 5.4: Rayleigh fading channel model

Figure 5.4 represents block diagram of a Rayleigh fading channel. Gs (t) is an input given to Rayleigh channel where Gr (t) represents and output of a channel. r (t) is a time variant multiplying factor and No (t) is the additive noise,

Hence, we can write an equation [19],

$$Gr(t) = Gs(t).r(t) + No(t) \dots (5.2)$$

For a particular application, change in parameters changes system. Hence, there is no firm method is available for Rayleigh fading channel technique but still it gives efficient output and hence mainly used for a study of multipath propagation of signal in air as well as underwater also.

A constant amplitude transmission signal can be given as [20],

$$Gs(t) = Re\left(A.e^{j2\pi fct}\right) \ldots \ldots \ldots . . (5.3)$$

Hence, the received signal from scattering multipath signals is given by,

$$Gr(t) = R(t).\cos\left(2\pi fct - \text{Ø}(t)\right) \ldots . . (5.4)$$

And,

$$X(t) = \sum a(t).\sin(\,2\pi fc\tau) \ldots \ldots \ldots \; (5.5)$$

$$Y(t) = \sum a(t).\sin(\,2\pi fc\tau) \ldots \ldots \ldots . \; (5.6)$$

Where,

$$R(t) = \sqrt{X^2 + Y^2}, \quad \text{Ø}(t) = \arctan(\tfrac{Y}{X}) \ldots \ldots \; (5.7)$$

In this a (t) and τ are the amplitude and delay associated with each scattered path.

The envelope R (t) has Rayleigh distribution and $\text{Ø}(t)$ has uniform distribution. This channel is known as, Rayleigh fading channel. Rayleigh channel is used to investigate the properties of underwater acoustic communication channel [20]. But sometimes there is a possibility that each distinct path may contain a dominant component and number of other sub components at that time due to inhomogeneity and microstructure of ocean medium, Rayleigh fading can't be used to study the behavior of underwater. In this thesis sub paths and dominant paths are not taken into consideration.

5.5 QPSK Receiver

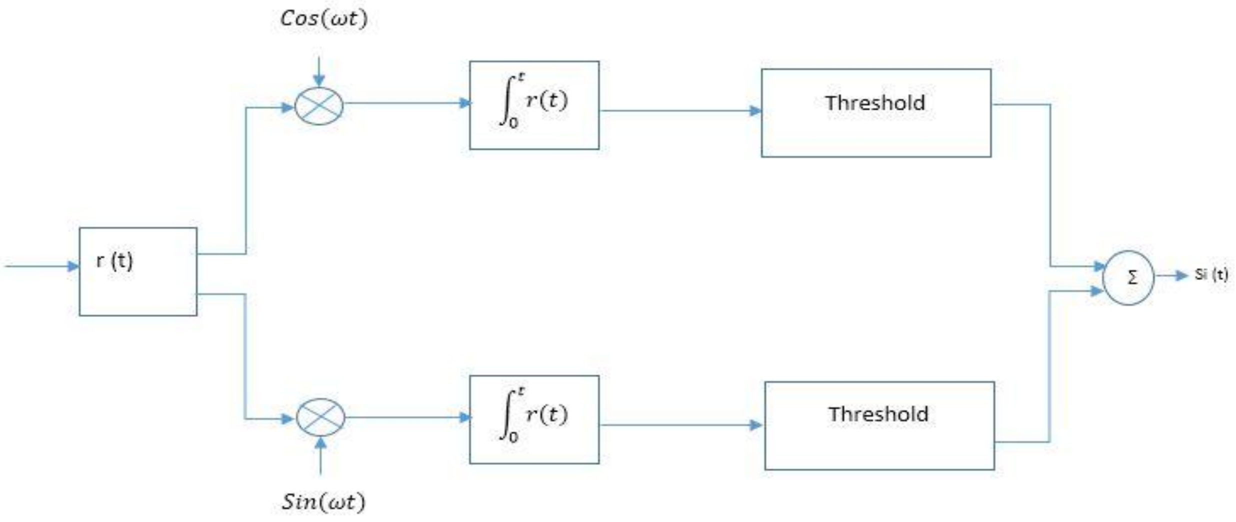


Figure 5.5: QPSK Receiver

When the signal is transmitted through a communication channel, to receive the transmitted signal QPSK receiver is used. When, the transmitted signal is collected at the receiver it is first multiplied with a reference frequency generator. The multiplied output with reference is integrated over one bit period using an integrator. Threshold detector takes a decision on each bit and finally Quadrature phase signal and in-phase signals are remapped to get the originally transmitted bit. [18]

5.6 BER calculation

When the data is received by the receiver, number of errors occurred after reception of data is calculated. Then the ratio of errors and symbols is obtained to plot SNR vs. BER plot

The ratio is obtained as,

$$\text{Ratio} = \frac{\text{No. of errors received at receiver}}{\text{number of symbols transmitted}}$$

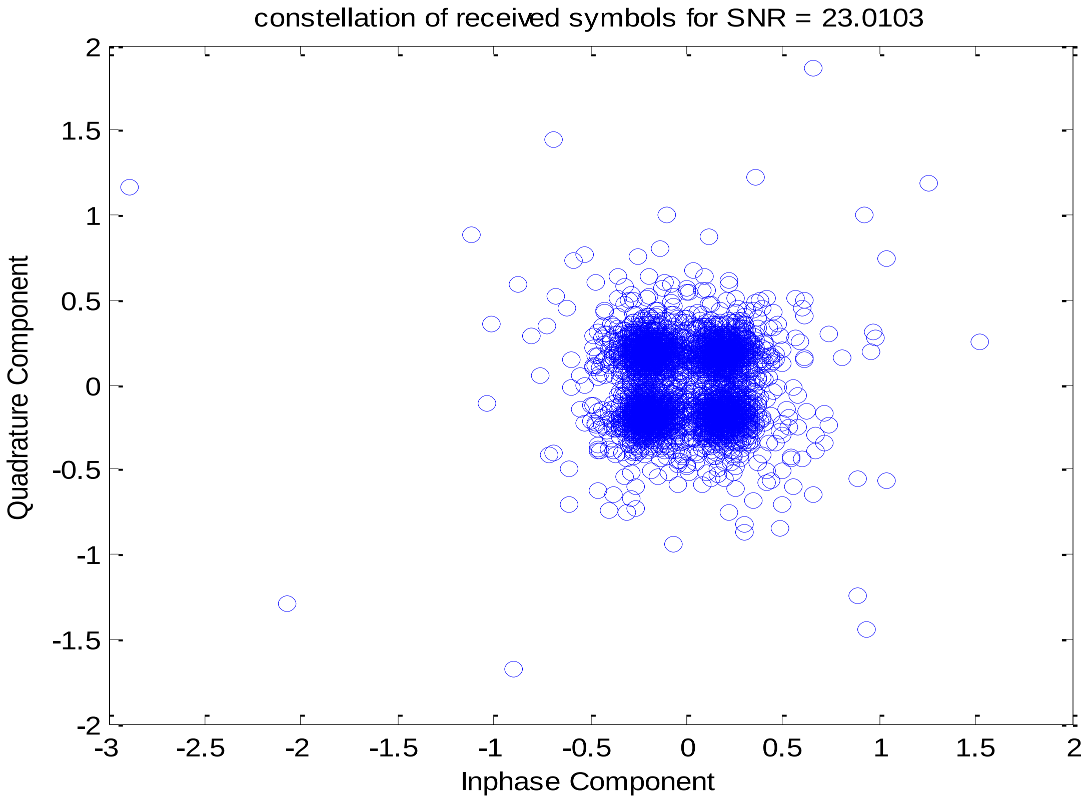
The BER plot for designed system is shown in figure 5.6

5.6 Final Result

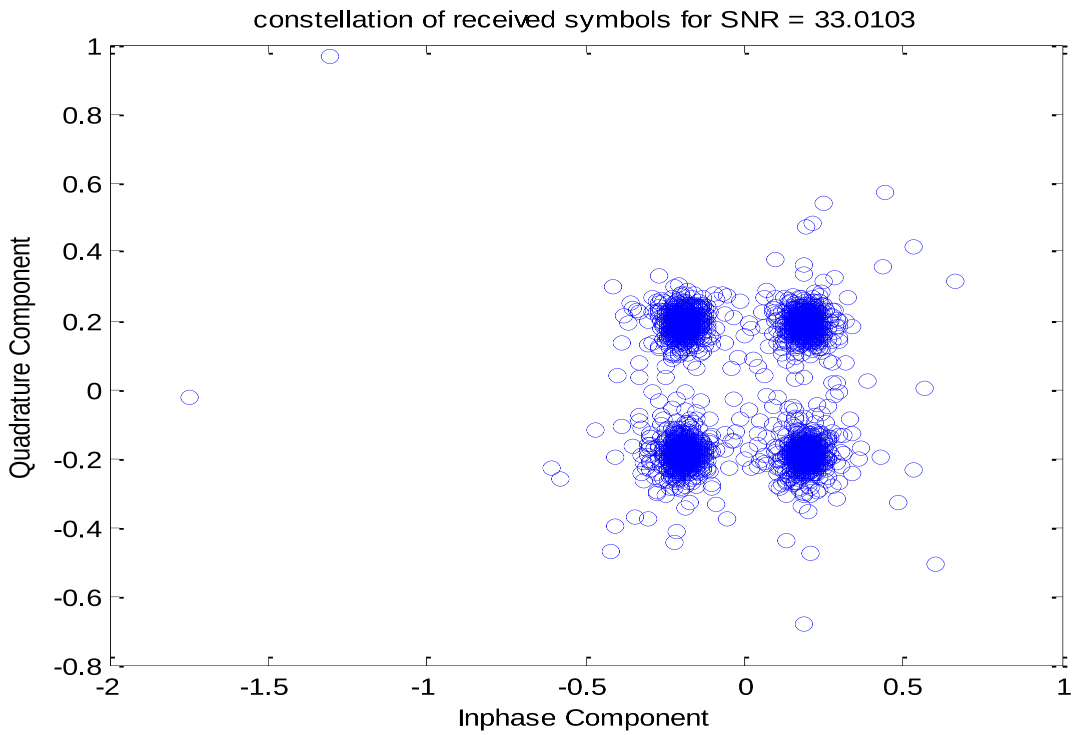
Constellation Plots for designed underwater wireless acoustic system using Rayleigh fading

From constellation plots it is completely seen that bits are received at receiver at SNR of 23 dB, 33 dB, 43dB and 53 dB out of which output at 53 dB is excellent and each bit can be separated to avoid errors. But generation of a power at such high SNR is practically impossible. Hence, we can say output at 33 dB is fair but contains lot of errors.

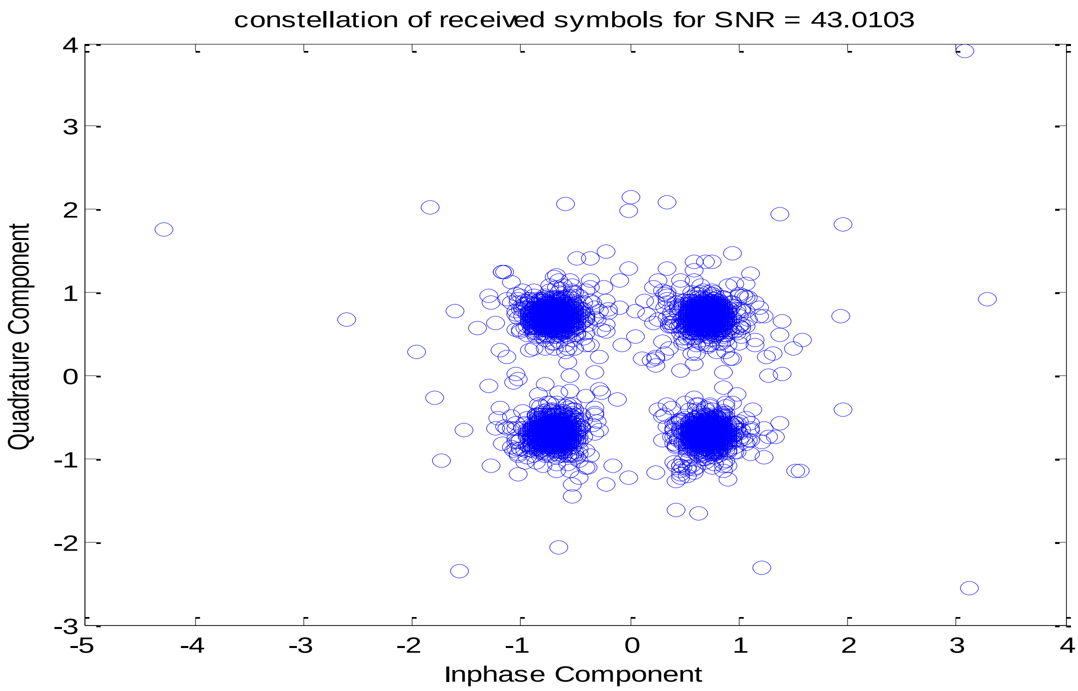
The basic problem in underwater wireless acoustic communication is attenuation is very high compare to terrestrial ground which affects system very badly and results into poor bit error rate. As shown in the first constellation plot at 23 dB all bits are very closer to each other and very hard to separate. So, all information can’t be recovered.

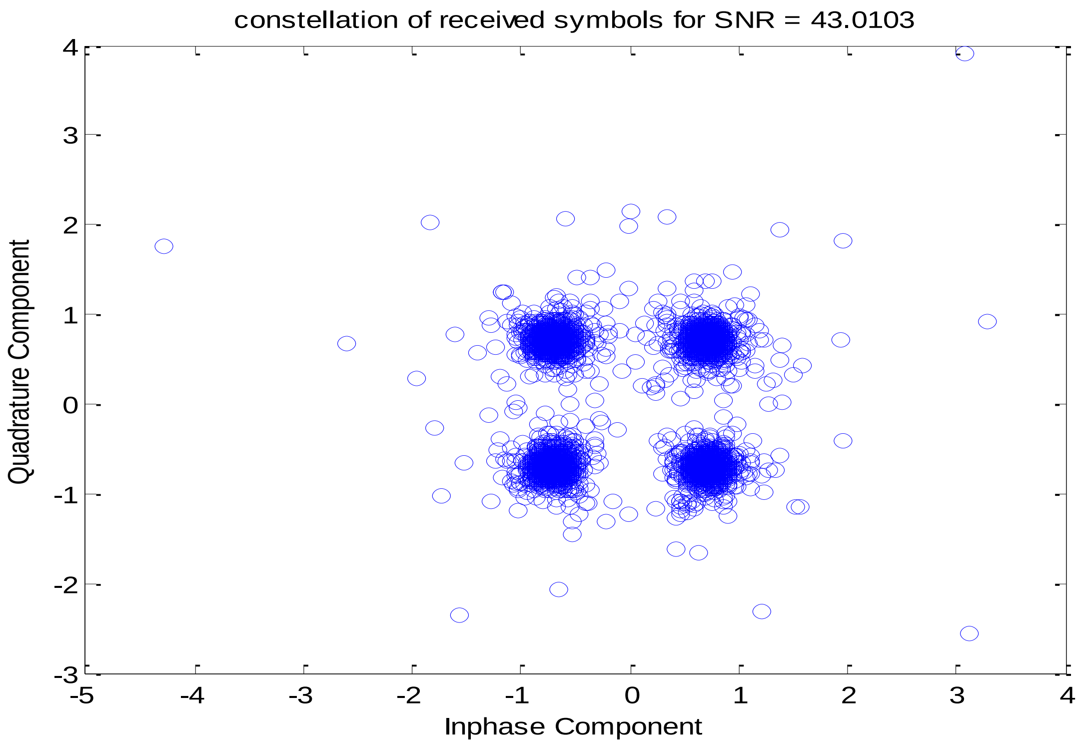


At 33dB recovery will be better than recovery at 23 dB but still symbols are very closer and mixed to each other. 33dB power can be practically generated hence we can use the system at SNR of 33dB with compromise of full recovery.



At 43dB and 53dB all symbols can be recovered but as discussed before generation of such high SNR is practically impossible because very high power will be required to produce this SNR. Which says that practically the BER of an underwater system is poor. So it is hard to recover all information that has transmitted through the transmitter at low SNR. It also affects data rate of system. Hence, from this result we can conclude that design of underwater wireless acoustic system at low SNR is very difficult.





SNR VS BER plot for these constellation plots is as shown in figure 5.6

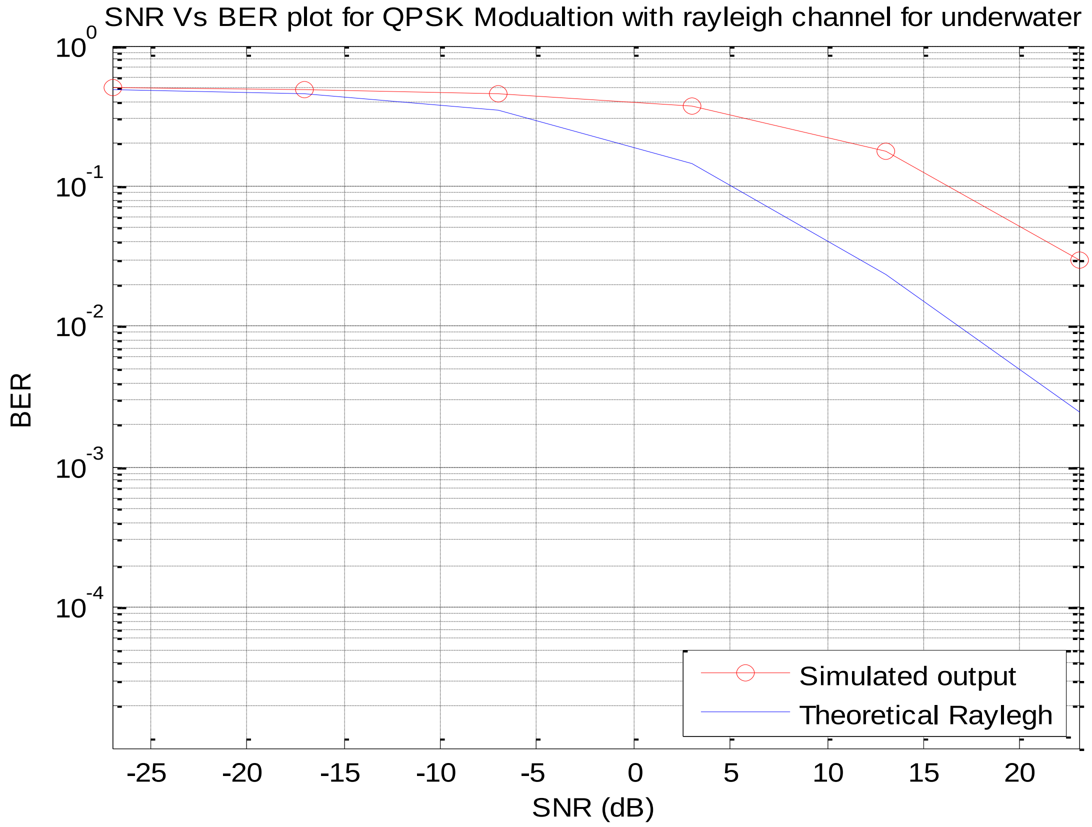


Figure 5.6: SNR VS BER plot for designed system of underwater wireless acoustic communication

6 CONCLUSION AND FUTURE WORK

Contents:-

- Conclusion
- Future scope

6.1 Conclusion

Thus, we say channel modulation for underwater wireless communication is extremely difficult as it mainly depends upon multipath propagation. The channel variation causes a degradation in bit error rate. Also, we don't have too much flexibility to change signal frequency range too high because most of the underwater parameters are dependent on frequency.

In underwater wireless communication, EM waves are not used in seawater although lot of research is done on them because acoustics gives excellent results with increase in velocity in underwater. Also, direct path transmission is almost impossible due to high attenuation components in salt water. And as attenuation, absorption and noise all are dependent on signaling frequency, it has to be carefully chosen for better performance. System cannot be robust if the channel variations affecting system are very high. Even for short distance communication also channel variations affects system very deeply. The complexity of a system is also very high. Channel degradation causes degradation in bit error rate (BER). Hence, the bit error rate for multipath propagation is poor.

6.2 Future scope

In this thesis, we considered that in underwater both transmitter as well as receiver are not moving. In future we can consider Doppler's effect by considering either one of the transmitter and receiver or both are moving in underwater. Also, we can develop a system for greater distance. An orthogonal frequency division multiplexing (OFDM) can be introduced to improve bit error rate and system performance. Different techniques like ray tracing technique, or use of Reed Solomon code can be used for studying the behavior of multipath propagation signals.

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